STREAMBANK PROTECTION

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SOIL CONSERVATION SERVICE
ENGINEERING & WATERSHED PLANNING UNIT
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STREAMBANK PROTECTION WITH STRUCTURAL MEASURES

By Leon F. Silberberger*

1. GENERAL

Purpose. The purpose of streambank protection work is to control bank cutting in order to protect adjoining land and improvements.

Information contained in this part of the handbook is intended to give work unit staffs some of the basic causes for streambank erosion and some of the structural measures that can be used to control it at critical sections.

The problem of stabilizing channel banks is a complex operation. It does not lend itself to precise design, and the success of a given installation is dependent upon the judgment, experience, and skill of the technician.

The discussion and methods contained herein are provided as a guide to the planner in recognizing the problem, and the applicable structural measures that can be used in its control. Except for minor site corrections where simple measures can be employed, the complexity of planning and construction require the assistance of an engineer.

2. INVESTIGATIONS

The best method of determining the behavior of a stream section is to observe the stream flow at flood stage. The direction of the main currents should be particularly noted at flood or near flood flow.

Fixed debris should be observed to determine what effect it has on deflecting flow. For example, a large fallen tree, root or stump in a certain position might be deflecting flows against the eroding bank.

Check overbank flows of surface water to determine if it is causing erosion damage to streambank.

Determine soil condition of the bank.

a. Will the soil support vegetation with the required fertilization?

b. On what slope will the soil remain stable without considering external forces?

c. Will the soil drain as a sand or gravel, or will it become slippery and unstable when wet?

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Observe stable bank conditions of stream with similar soils to the eroding section. This observation will help determine the desirable slope to use on the streambank to be protected.

Check causes of bank erosion. The bank may be receding by any one or a combination of the following causes.

a. Washing away of soil particles of the bank by current or waves (erosion).

b. Sliding due to the increase of the slope of the bank as a result of erosion and scour.

c. Undermining of the toe of the lower bank by currents, waves, swirls, or eddies as are caused by debris, fallen trees, etc., and followed by collapse of overhanging material deprived of support (scour).

d. Sloughing or sliding of slope when saturated with water and overloaded by brush and trees. This is usually the case during floods of long duration or following long periods of precipitation.

e. Sliding due to seepage of water flowing back into the river after the flood recedes. The internal shearing strength is considerably decreased owing to saturation, and the stability is further decreased by the pressure of seepage flow.

f. Piping in a sub-layer due to movement of ground water to the river which carries sufficient material with it.

It is important to recognize the basic causes of bank recession so that the method of treatment used will effectively control the cause.

Streambank survey data obtained during an investigation might be recorded on a form similar to Figure 1. The use of a form of this type will assure that the essential information is obtained.

3. LEGAL AND ECONOMIC ASPECTS

The flow line of a stream is often a property boundary and this must be considered in planning structural measures.

The economic soundness of any project should be estimated at the very outset of planning. The estimated cost of control should be weighed against the possible benefits.

4. TREATMENT OF STREAMBANKS

The following information is a review of some of the important points that must be considered when planning channel protection work.

It is a well-established viewpoint that the success of the stabilization of the bank of an alluvial stream is dependent on starting work at some stabilized point and progressively working downstream to another stabilized point. Stabilization of banks at isolated locations in a haphazard manner has not met with other than temporary success.

Streambank work done on any segment of a stream will be affected by the condition of the stream above and below the segment being considered. If the entire length of an eroding section of the stream cannot be protected, work should be started from a section that is controlled such as a bridge section. Planning should be accomplished for the entire length of stream upon which work is to be done even though work is to be completed by short segments. The completed work will then fit into the overall plan as each section of work is completed.

It should be kept in mind that the most efficient method of channel protection is one which guides rather than opposes the course of the stream.

Past experience with various types of bank protection work has indicated that the undermining or scouring of the foundation material in the installation by high velocity currents has been the original cause of most failures.

The greatest scour depths occur on the outside of curves. Scour areas also occur where the high velocity section of a stream is forced to travel adjacent to the protective works.

In bank protection work where only the channel sides are protected, there is always danger in all but low velocity streams of local or temporary bottom scour occurring to some extent below the normal stream bed and the probability that the stream bed material will become unstable as a revetment foundation for some depth below the normal bed elevation. Therefore, the bank protection measures must be extended down to a point below the probable maximum depth of scour or some other provision made to protect it from being undermined. Placing the toe of the structural lining a minimum of two feet below the existing stream bed should give good protection against undermining.

The use of grade control sills constructed in the stream bed is an effective method of controlling the channel bed in areas of the stream where scouring is expected.

Before structural measures are undertaken, remove large overhanging banks and fallen trees that may cause current deflections. Often such clearing followed by replanting of adaptable vegetative material will provide sufficient stabilization to reduce or eliminate need of structural measures.

5. REVETMENT OF STREAMBANKS

Bank revetment of streambank has proved reliable for controlling bank recession on streams in the northeast. This revetment work is usually supplemented by vegetation. The amount of vegetation used and the place of application is dependent upon the bank conditions.

6. ANCHORED TREE REVETMENT

The use of trees cut near the site of a streambank protection job will often provide satisfactory bank protection when properly installed. This type of revetment work requires considerable labor and the use of equipment for cutting the trees and moving them into proper position along the bank. The period that it will give protection is dependent upon the type of trees used and the effectiveness of vegetation established on the bank. See Figure 2, which illustrates an acceptable method of installation. Use trees with a trunk diameter of 12 inches and above. The type of equipment available to move trees into place will limit overall size of trees that can be used. This method usually can be accomplished with available farm equipment.

7. LOG - ROCK REVETMENT

This type of revetment work requires the use of timber cribbing, back filled with rock and coarse gravel. Its construction also requires considerable labor, and its useful life is dependent upon the period the logs will hold the rock in place before rotting. See Figure 3 for an acceptable method of doing this type of protection work.

8. DUMPED ROCK RIPRAP

This type of revetment work requires a source of rock that can be obtained at low cost. Access roads near the stream channel must be such that rock can be hauled to the streambank and either dumped over the bank or along the edge. If the job is of sufficient size to require large quantities of rock, it is necessary that the operation be set up to accommodate regular deliveries to the job site. In some cases, the banks may be too weak to support a truck loaded with stone, thereby preventing the dumping of rock directly over the streambank. In such cases, the rock may be dumped as close to the edge as possible and pushed over the edge with a bulldozer. The use of a bulldozer may also be used to advantage in the placement of rock by size as it is pushed over the bank. It is desirable to get the larger stones in the bottom of the revetment work and thereby provide a stable toe section. This can be accomplished to some degree with a bulldozer.

This type of bank protection requires more stone per square yard of bank protection than machine placed riprap but usually requires less labor and equipment operating hours.

9. MACHINE PLACED RIPRAP

This type of riprap is placed using a clam shell bucket on a power crane. It is placed on a prepared sloped bank to a minimum design thickness of 12 to 18 inches. The larger stones are placed in toe trench at base of slope. This method requires a good operator to get uniform placement. The toe trench can usually be dug with clam shell and filled as the machine moves along the slope. The smaller rocks are placed last on top of larger stones to fill void spaces. See Figure 4.

The bank sloping is usually accomplished with a power crane using a dragline bucket. A perforated dragline bucket will work best since it will not pick up water in the sloping operation and cause material in

STREAMBANK SURVEY DATA

Location ______________________ Aerial Photo No. ______________________

Photo Location No. ______________________

Comments

____

____

____

____

____

____

I. Bed

Composition — A. Surface — Gravel ☐
Rock ☐
Clay ☐
Other ________ ☐

B. Sub-Surface

1 2 3

C. Unusual Gradient Conditions ______________________________

II. Bank

A. Composition

Indicate seepage points. Indicate Location Samples were taken.

Sketch Scale

Horizontal ___1" = _____

Vertical ___1" = _____

____

Direction of Flow

Sketch

Average bank height _____ Approximate bank length _____ Average bank slope _____

III. Structural

1. Slipping — Serious ☐ Minor ☐ None ☐
2. Undercutting — Serious ☐ Minor ☐ None ☐
3. Surface Erosion — Serious ☐ Minor ☐ None ☐

IV. Flood Plain — Composition

Samples# ______________________________

Date ______________________ Name ______________________

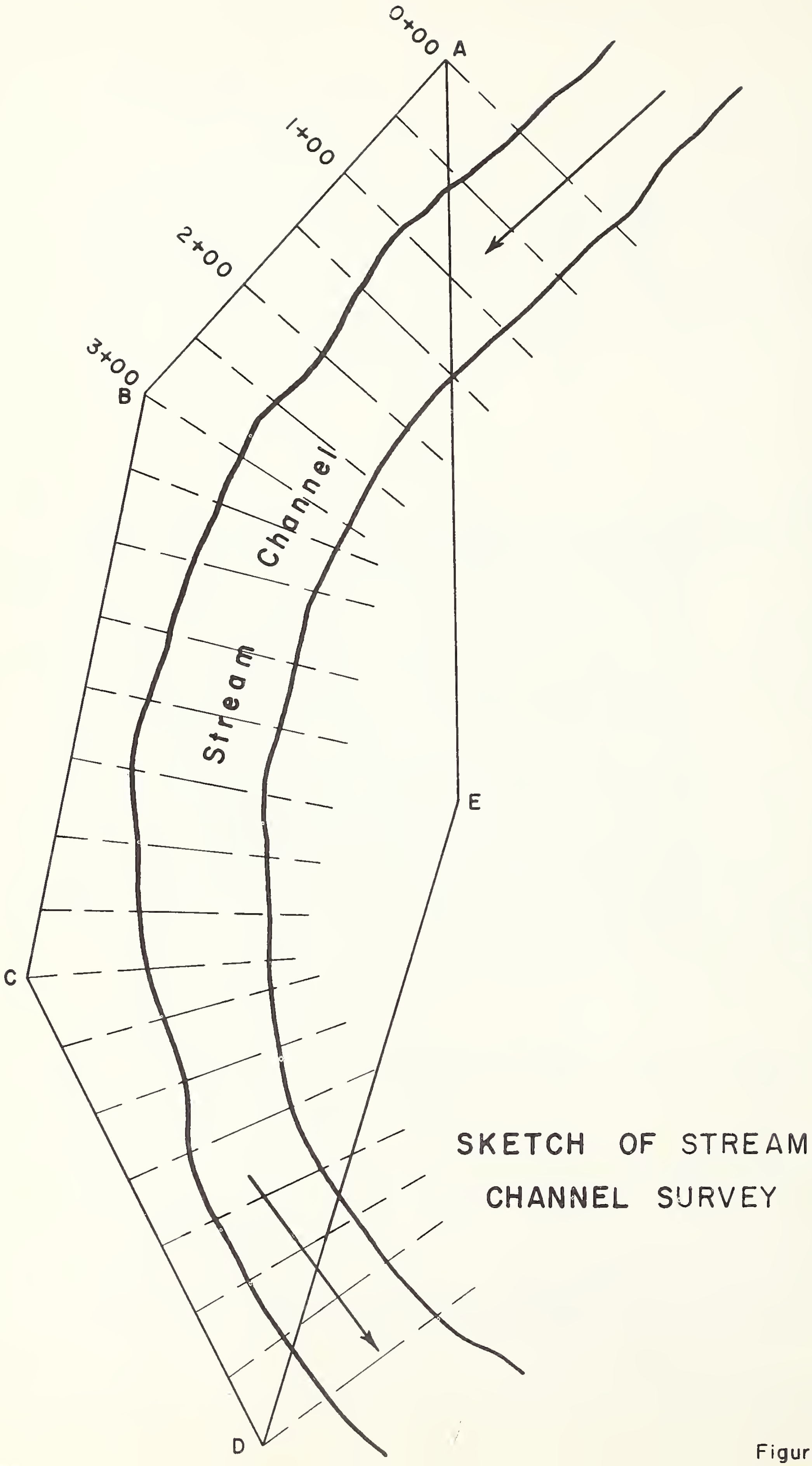
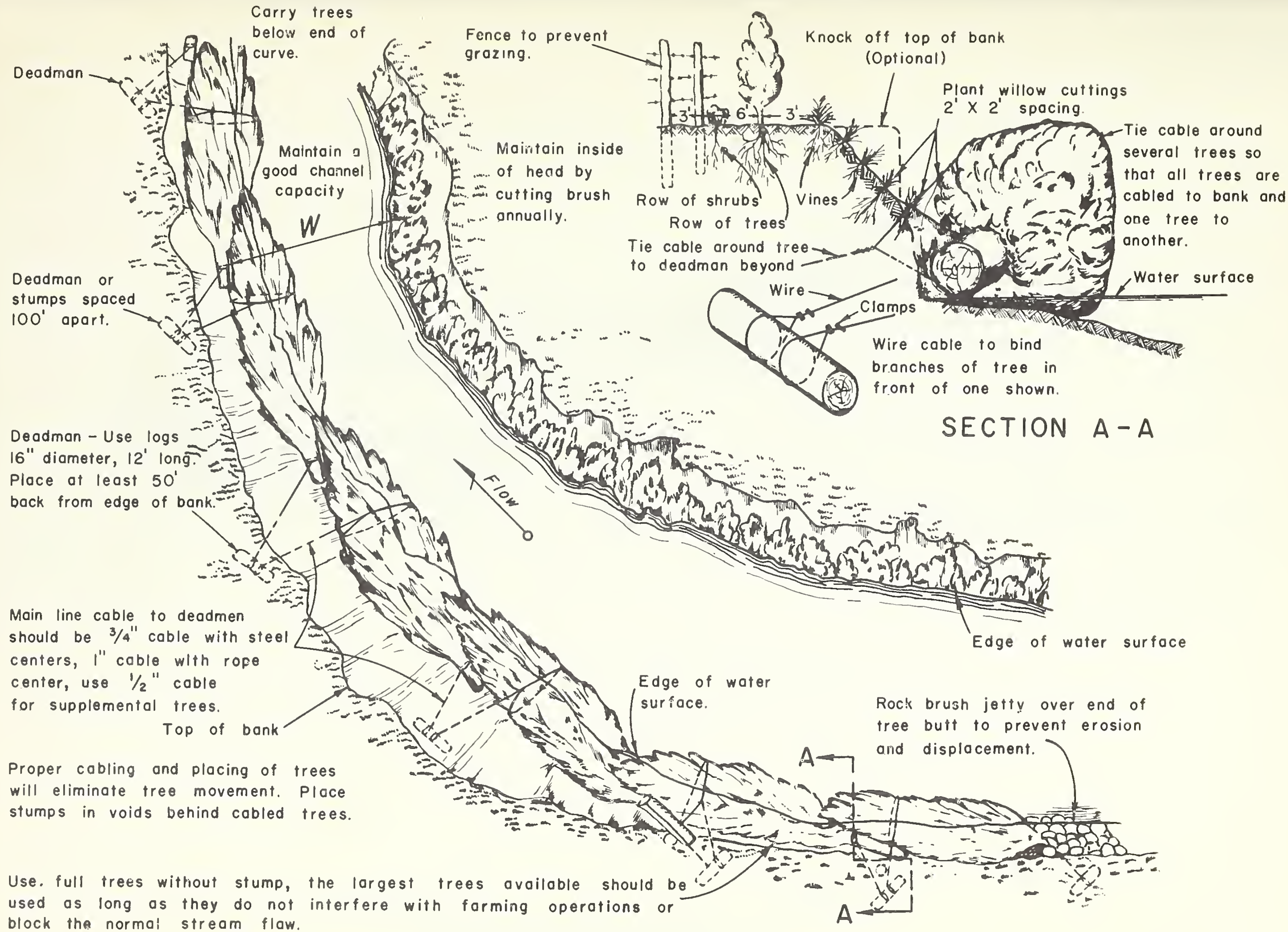

0+00
A
1+00
2+00
3+00
B
Channel
Stream
E
C
D
SKETCH OF STREAM
CHANNEL SURVEY

Figure A-1

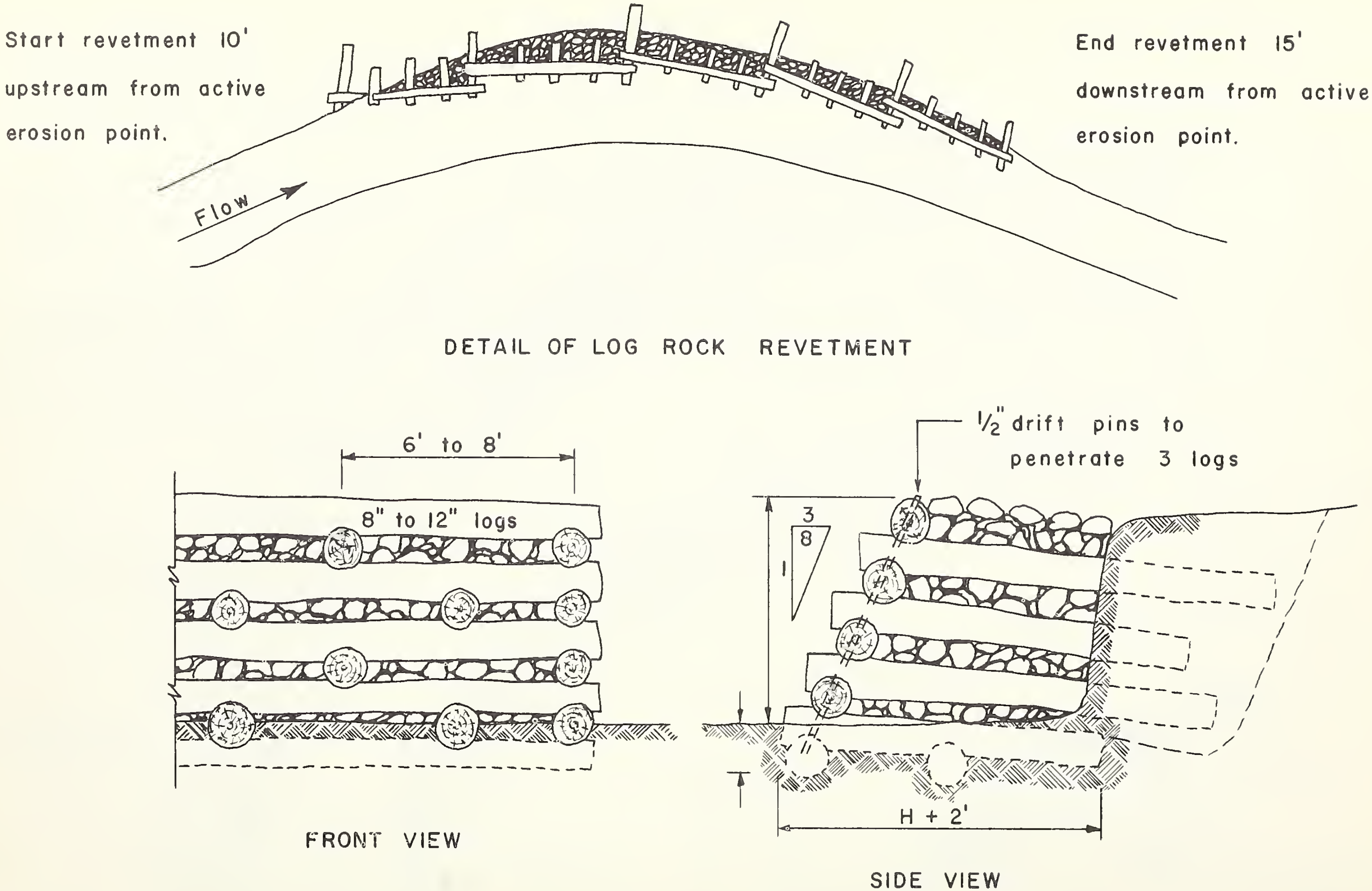


STREAMBANK EROSION CONTROL ANCHORED CUT TREE REVETMENT

TREES TO BE USED SHOULD BE PRIMARILY HARDWOOD, ELM, WILLOW, OAK, OR MAPLE

Figure 2

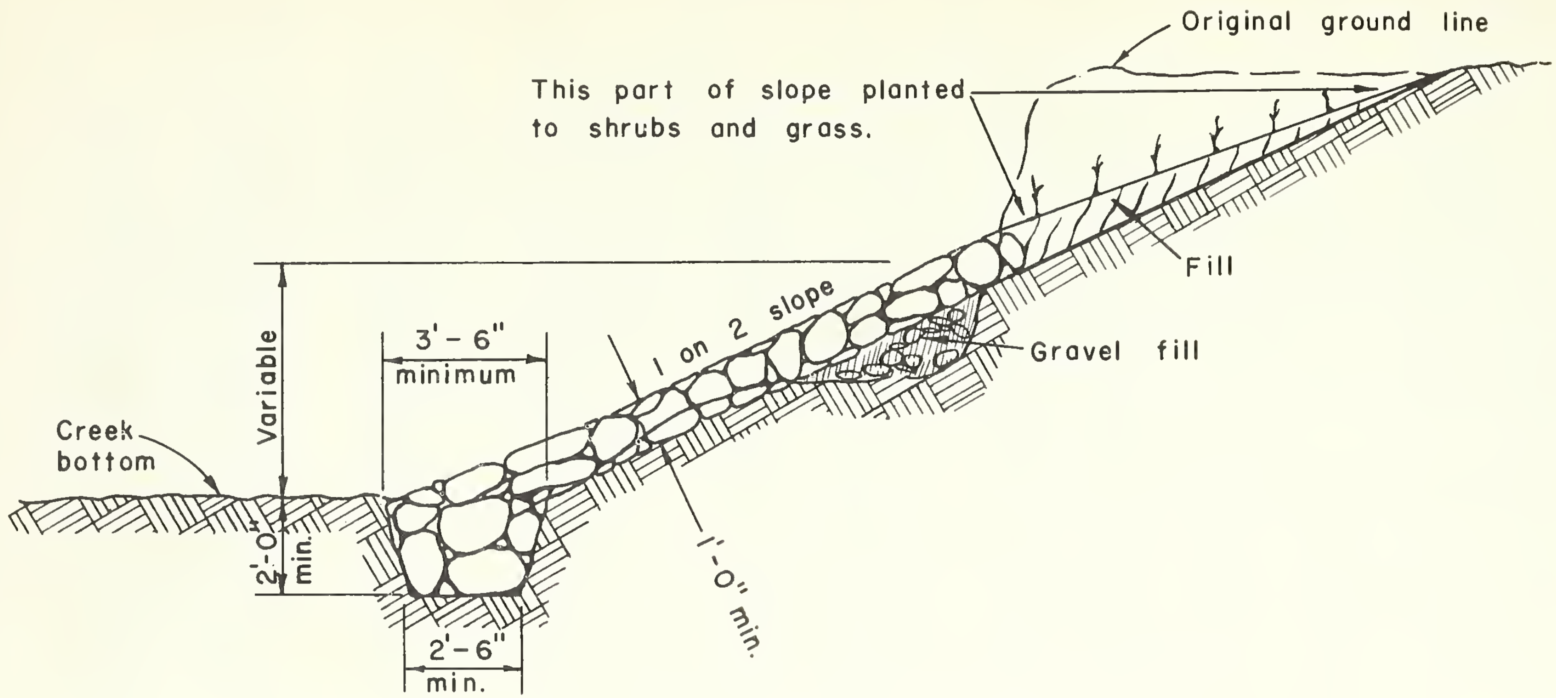
Figure 2



SKETCH OF USE AND DETAIL OF LOG ROCK REVETMENT

Figure 3

Figure 3



SKETCH SHOWING TYPICAL RIP-RAP SECTION

Figure 4

Figure 4

work area to become wet and difficult to re-handle or work around.

10. MACHINE PLACEMENT OF EXISTING STREAM CHANNEL COBBLES

This type of streambank protection consists of placement of coarse gravel and cobbles found in the stream channel against the eroding banks. The stream bed material when used for this purpose should have

a. A large amount of cobbles, 6 inches in diameter and above, with grading down to coarse gravel.

b. Deposits of sufficient depth so that the removal of material to protect the bank will leave ample material in the bed to re-shingle.

Usually a depth of 3 to 4 feet in the stream bed will provide material to protect one bank and leave sufficient material for the channel to shingle. The bank material should be graded smoothly to the bank protection material so that protrusions or small vertical bank areas will not furnish resistance to flood flow and cause the bank to erode.

The material should be placed against the bank at a minimum slope of 2 on 1. The flatter the slope, the better the chance of this type of material to become stabilized. See Figures 5 and 6.

In high velocity streams, special consideration must be given to the effect of removing the cobbles or alteration of the stream bed material.

Before undertaking any extensive operations using cobbles from the stream bed, a small test job should be completed and its effectiveness observed for a year or so. The results of work that have been completed by other organizations, such as Highway Departments, should be inspected for clues on the effectiveness of the bed material.

11. RIPRAP STONE

Field experience indicates that both angular (crushed limestone) and rounded (river cobbles) particles have been used for revetment material with equal success.

The riprap stone should be sound and dense, free from cracks, seams, and other defects that would tend to increase deterioration from weathering, freezing, and thawing or other natural causes. Stone should be reasonably well graded from the minimum size to the maximum. In order to avoid the use of thin platy rock, the stone that is selected for use should be of a type that neither the breadth nor the thickness of individual stones will be less than 1/3 of its length.

12. FILTER BLANKET

It has been a generally accepted practice to place a gravel blanket under riprap to protect subgrades of clay, silt and fine sand from being

eroded. There will always be conditions where this blanket will be needed; however, certain experiences of the Corps of Engineers and the Service indicate that a well-graded rock of various sizes down to spalls or chips and gravel will substitute for the blanket. An engineer should be consulted when a determination needs to be made on the use of a blanket under riprap.

A 6-inch layer of well-graded pit-run gravel will usually make a satisfactory blanket under riprap where a blanket is required.

13. SEEDING AND WILLOW PLANTING

If possible, it is well to schedule completion of construction jobs early enough so that seeding can be established before winter. The application of mulch will also greatly aid in the establishment of vegetation. It has been found that wood chips make an ideal mulching material for this work.

It is also good practice to provide for stockpiling topsoil or fine material from sloping operation for use in fitting the area of the bank to be planted.

Unfavorable seeding dates--that is, work that is completed at other than seasonal seeding periods--can be successfully established by the use of irrigation and the application of nitrogen.

The application of ammonium nitrate at the rate of 50 lbs. per acre through an irrigation system will help in getting establishment of vegetation. This should be applied at monthly intervals until seeding is well established.

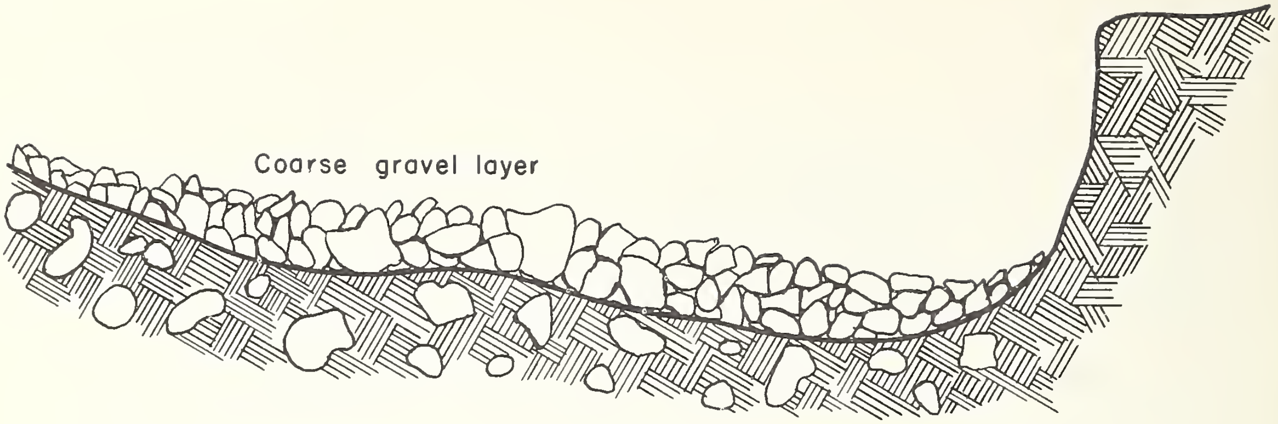
Mixtures of legumes with grasses have provided good cover on streambanks. The following mixtures have given good results. Locally adaptable seed mixtures and plantings should be used.

Experience has established that a combination of grasses and woody plantings is superior to woody plantings alone. A quick effective cover will be provided by the grasses, with the willow providing protection after establishment against debris, ice, etc.

14. MAINTENANCE

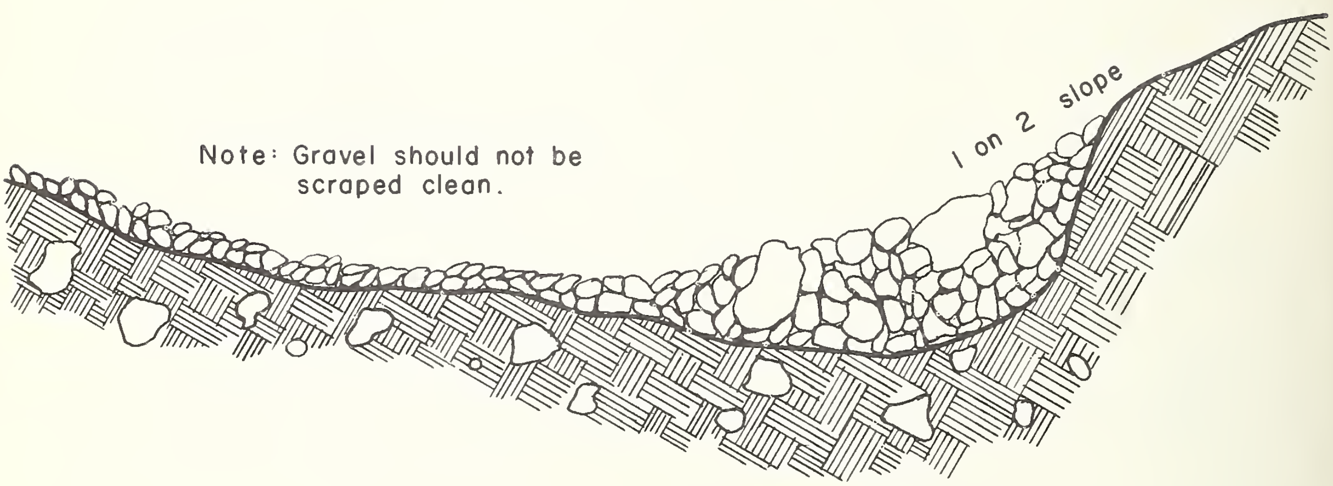
All types of streambank control require maintenance, and the necessity of systematic maintenance of installations cannot be overemphasized.

Installations should be inspected periodically and, in all cases, following heavy flood flows. A damaged area of riprap will "unravel" rapidly if not promptly repaired.



SECTION BEFORE GRAVEL TOE PROTECTION

Figure 5



SECTION AFTER GRAVEL TOE PROTECTION

SKETCH OF STREAM CROSS-SECTION SHOWING HOW COARSE GRAVEL IS PLACED AGAINST CAVING BANK

Figure 6

Willows and other trees planted for bank protection should be cut off before they reach a diameter where they are no longer pliant (greater than 2"). Brush growing on the inside of curves should be cut down periodically.

15. TREATMENT OF HIGH BANKS

The application of revetment on banks which are too high to be practically sloped can be protected from recession by using two methods; one, the embankment bench method, and the other, the excavated bench method. See Figures 7 and 8.

The embankment bench method involves the placement of a gravel bench along the base of the eroding bank. The elevation of the bench should be set not lower than the height of the opposite bank and, where practicable, 1 to 2 feet higher. This gravel bench provides drainage at the base of the bank and a stable fill to support the riprap. It provides a working space for the power crane to place the riprap stone. The embankment bench method requires that the convex side (low bank) of the channel be excavated to compensate for the reduction in area taken by the bench projection. See Figure 7. The high bank is left to slough down on the prepared bench until it has established a slope that is stable enough to be planted.

The excavated bench method (Figure 8) is used in similar situations to the embankment bench. This method does not require the gravel fill material nor the enlarging of the channel to compensate for jutting bench area.

Some of the factors to consider when deciding on which of the bench control methods is best adapted to a given site are:

a. Accessibility of the area.

b. Availability of gravel fill.

c. The greater element of risk is in the embankment bench method due to the fact that the gravel bench is subject to considerable damage should a flood occur before the riprap is in place.

High banks which are subject to surface water flow can be protected by the use of diversion ditches constructed along the upper area of bank. Water from springs which erode the high banks should be diverted to the stream by collecting the water and piping it to the stream channel.

16. TREATMENT OF LEDGE BASE STREAMS

Segments of channel which have rock or shale beds with banks eroding make it necessary that special methods be used to assure that the toe of the riprap will remain in place. Two methods which have worked successfully are:

a. Steel Dowel Method. This method utilizes No. 8 steel reinforcing rods, 3 feet in length, grouted with concrete in drilled holes.

See Figure 9. When this method is used, it is required that the large stone in the riprap be placed along the outer edge of the toe. The steel dowels are placed at random in position against the large rocks which act as key stones in the toe.

b. Precast Toe Blocks. This method utilizes precast concrete blocks. See Figures 10, 11 and 12. The precast blocks should be 12 inches square and 5 feet long. Reinforcing rods extend 12 inches from each end of the block to form loops. These steel loops are placed so that they encircle steel bars grouted in place. The steel bars should be a minimum of 3 feet in length and 1 inch in diameter. In the case where a 3 foot bar is used, a minimum of 2 feet should be concrete grouted in drilled holes. Since the blocks are of uniform length, the bars are grouted in place on 6'-6" centers. A wooden templet should be used when drilling holes to assure proper spacing of the steel bars. The precast blocks are easily placed using a 2-hook sling on a power crane. Wood planks should be used to protect the concrete blocks during the placement of the stone so as to avoid the possibility of damage to the blocks by dropping a stone on it during the revetment operation. In channel sections where the bed is uneven, the steel loops may be bent so that they anchor to the steel bars.

17. CHANNEL CUT-OFFS

The use of channel cut-offs may be necessary in some cases of improvement work. For example, when the cost of cutting the new channel and protecting it with riprap is less or no greater than protecting the existing channel, and it is necessary to improve the hydraulic characteristics of the channel.

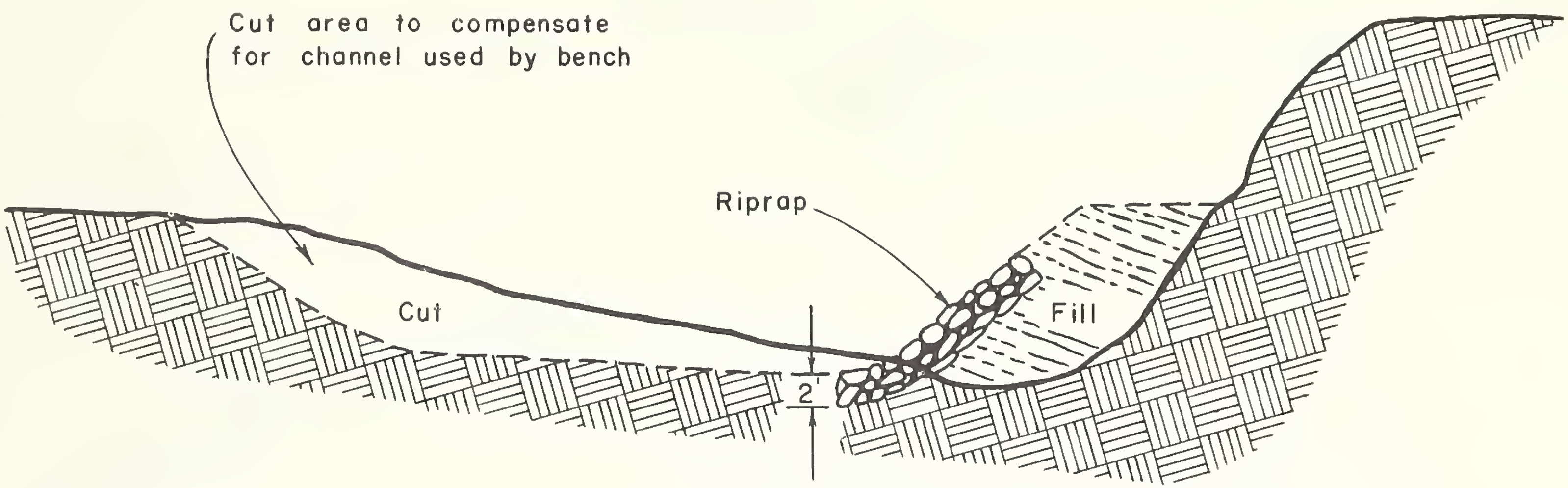
The straightening of a stream channel, except in areas of very flat land and channel reaches, is a risky undertaking and should not be done until a thorough study of the channel is made. See Figure 13. It may be seen from this Figure that shortening the reach of a channel may double the slope. When a decision is made to straighten a channel, consideration must be given to the protection of the channel bed from degradation. In the case of small channels, sills made of logs or rock may prevent degradation of the channel until it shingles. In a larger channel, a more elaborate sill system may have to be used similar to Figure 14.

18. OTHER STRUCTURAL MEASURES

Walls and groins of timber, concrete and gabions may also be used when a high degree of protection is required. Their use, however, is seldom applicable to agricultural installations.

19. QUANTITY ESTIMATING TABLES

The following charts may be used in estimating quantities of riprap needed; K in cubic yards, S is distance along surface of riprap. See the following tables.

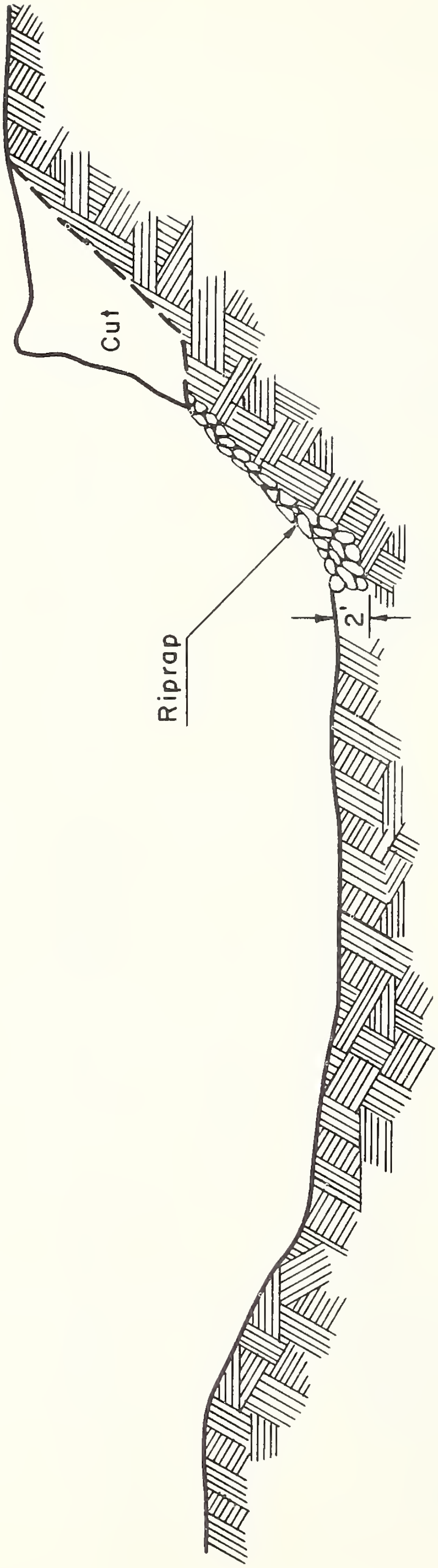


EMBANKMENT BENCH METHOD OF PROTECTING HIGH BANKS

Figure 7

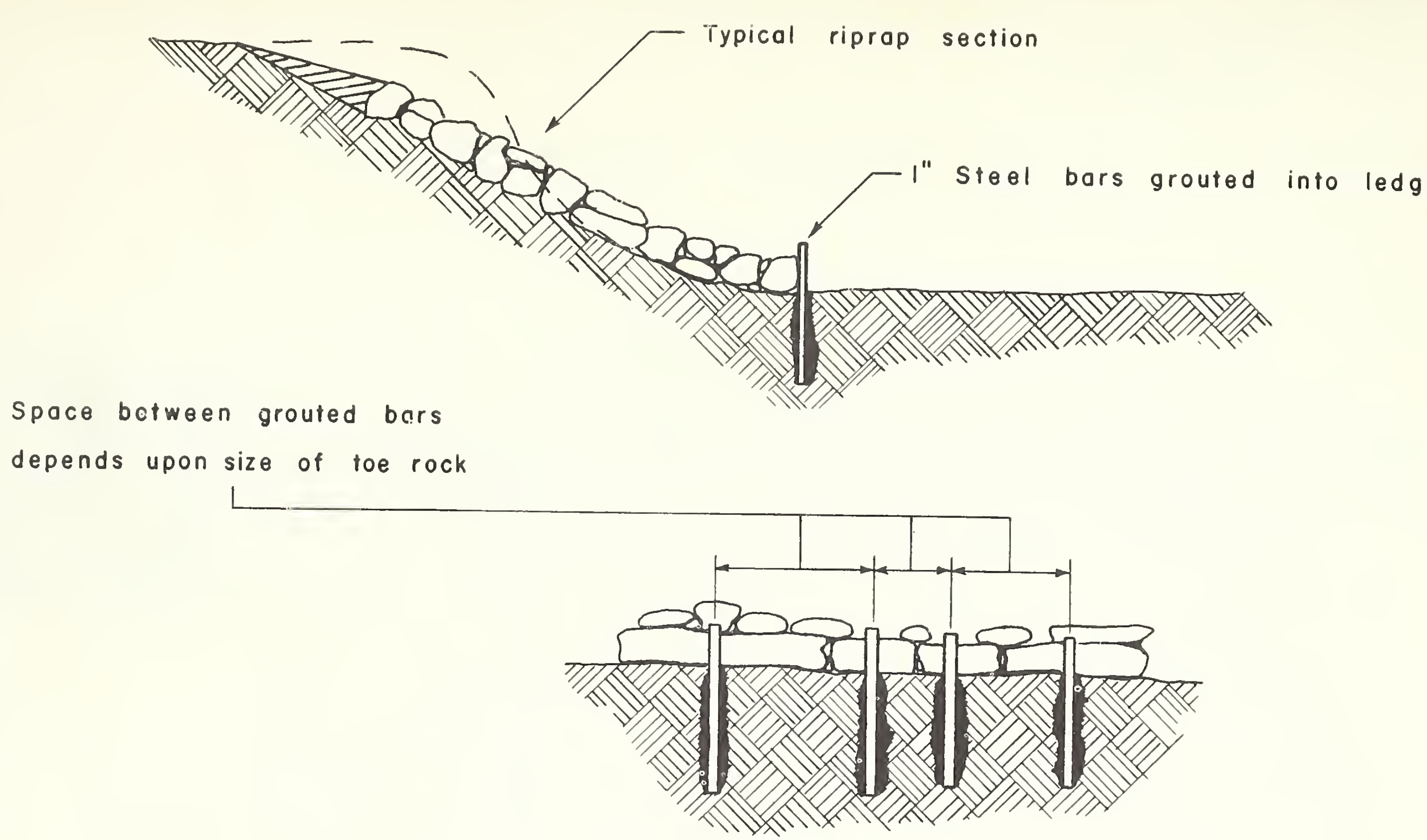
Figure 7

Figure 8



EXCAVATED BENCH METHOD OF PROTECTING HIGH BANKS

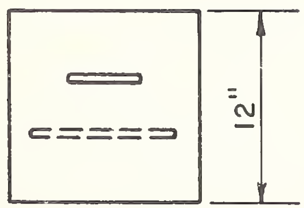
Figure 8



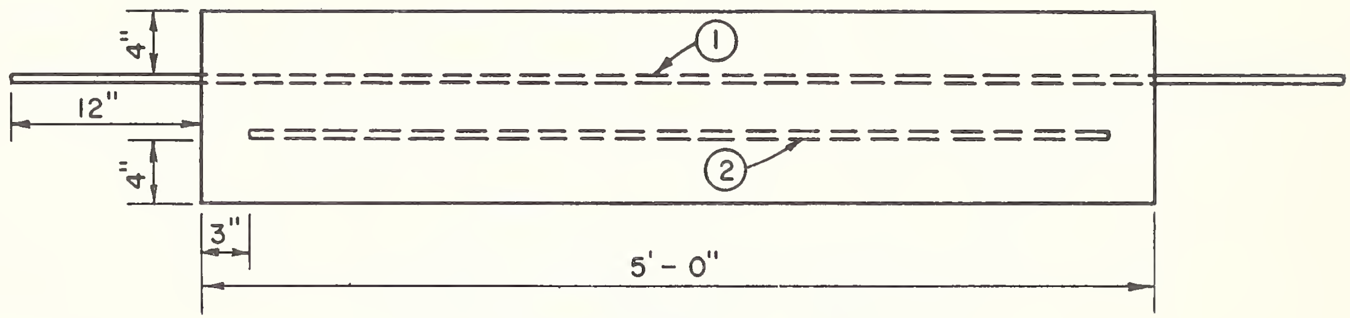
STABILIZING TOE ROCK WITH GROUTED STEEL BARS

Figure 9

Figure 9

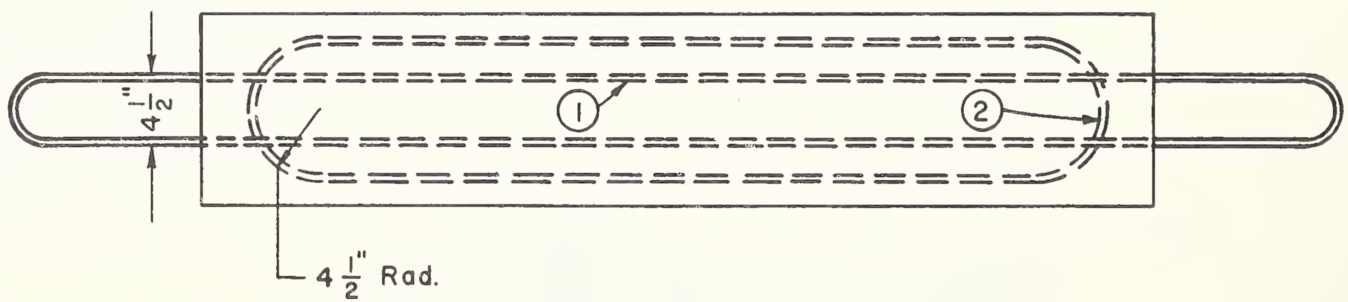


END VIEW



SIDE VIEW

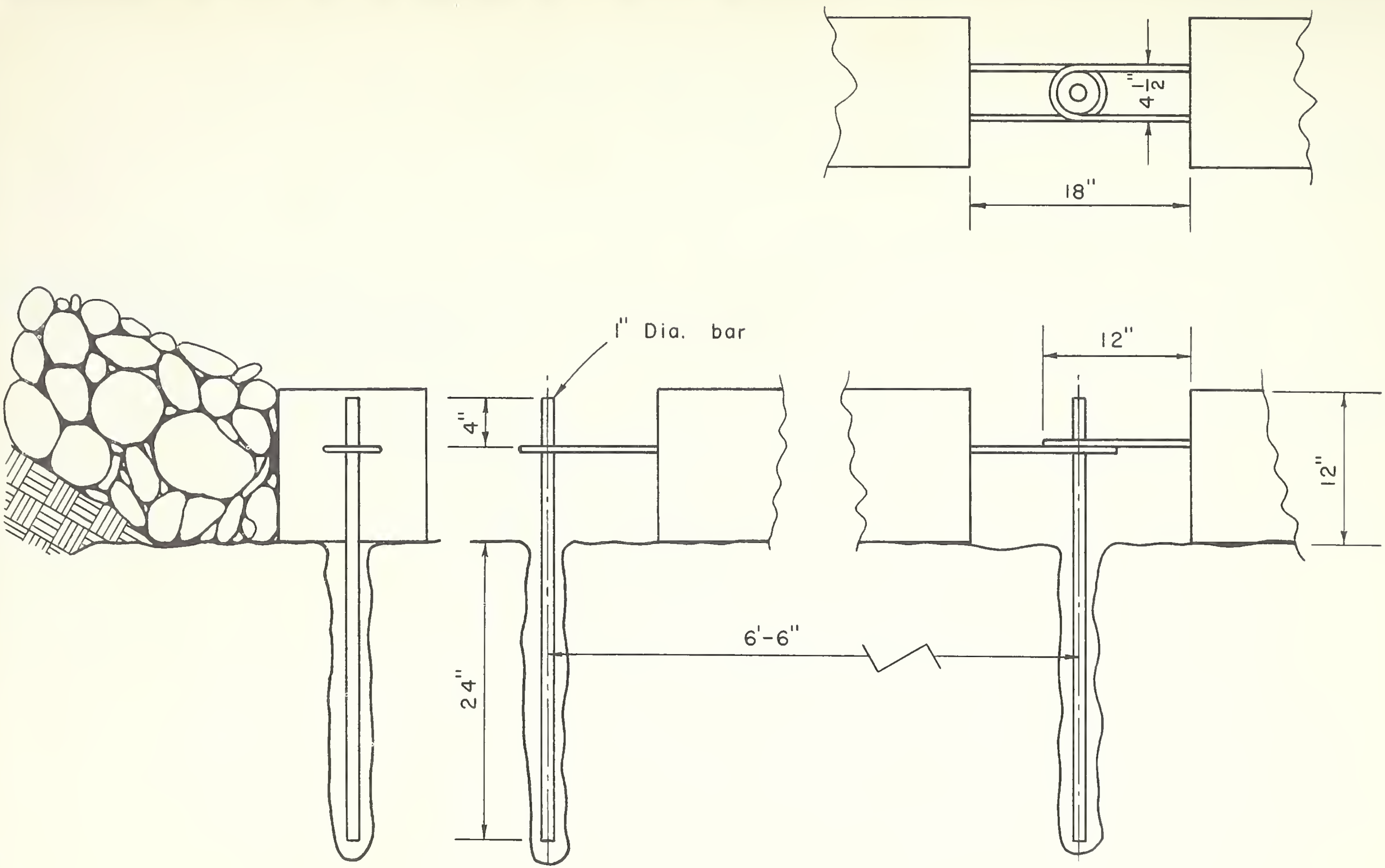
STEEL SCHEDULE			
Mark	Quan	Stl.	Length
1	1	$\frac{5}{8}$"	11'-0"
2	1	$\frac{5}{8}$"	12'-0"



TOP VIEW

DETAIL OF PRECAST CONCRETE FOOTER

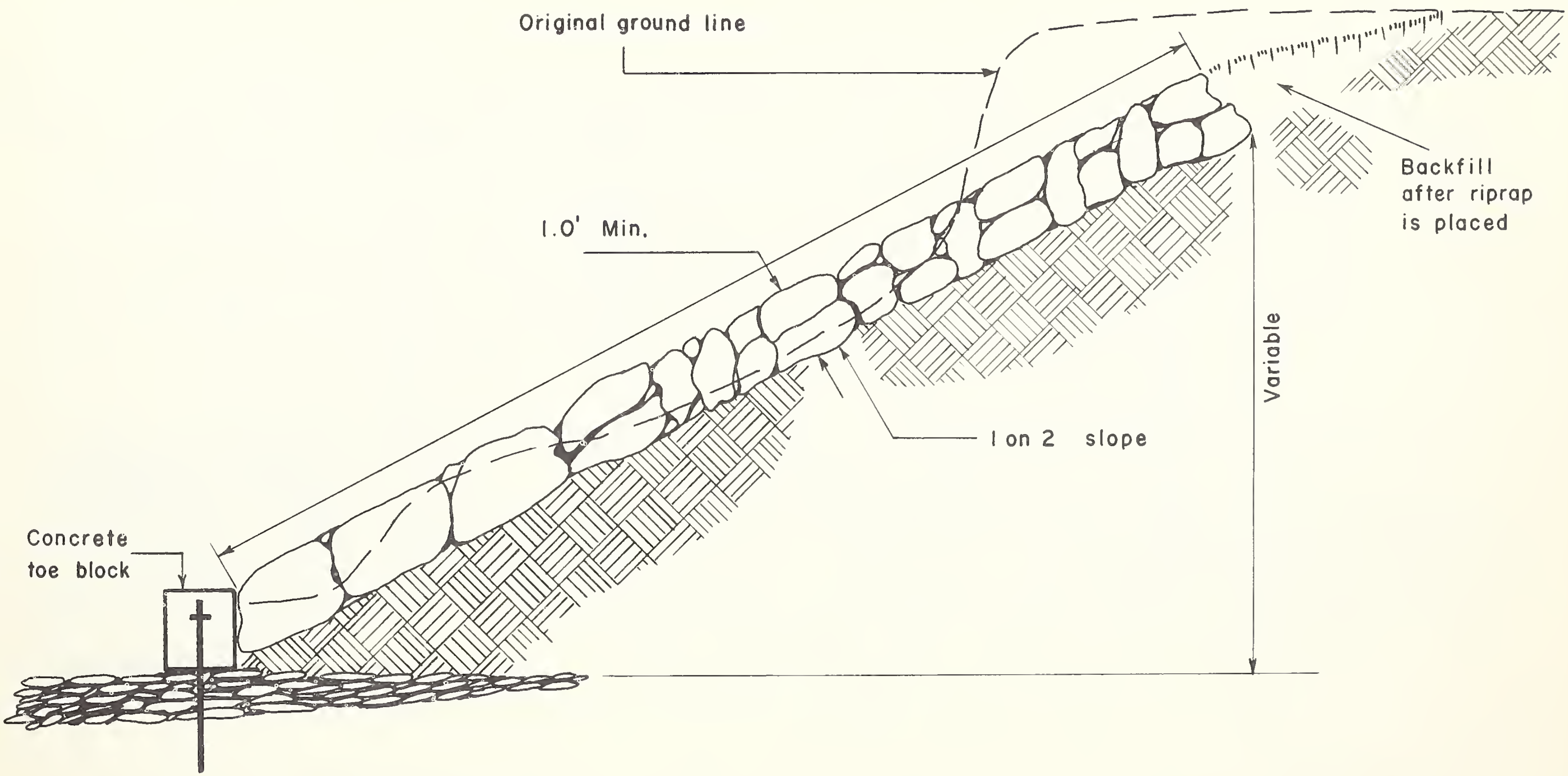
Figure 10



INSTALLATION OF CONCRETE TOE BLOCKS

Figure 11

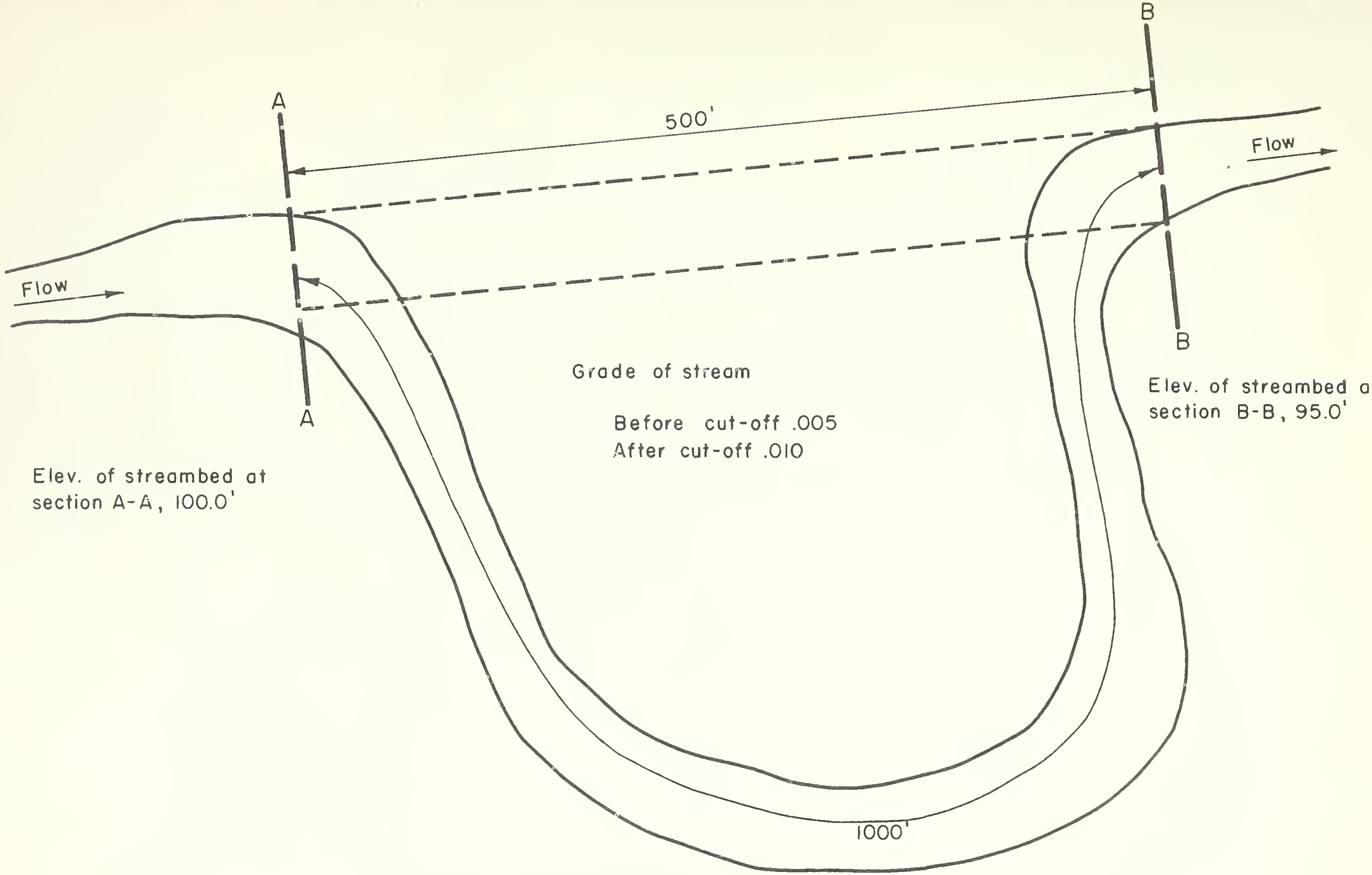
Figure 11



RIPRAP SECTION TO BE USED WITH CONCRETE TOE BLOCK

Figure 12

Figure 12

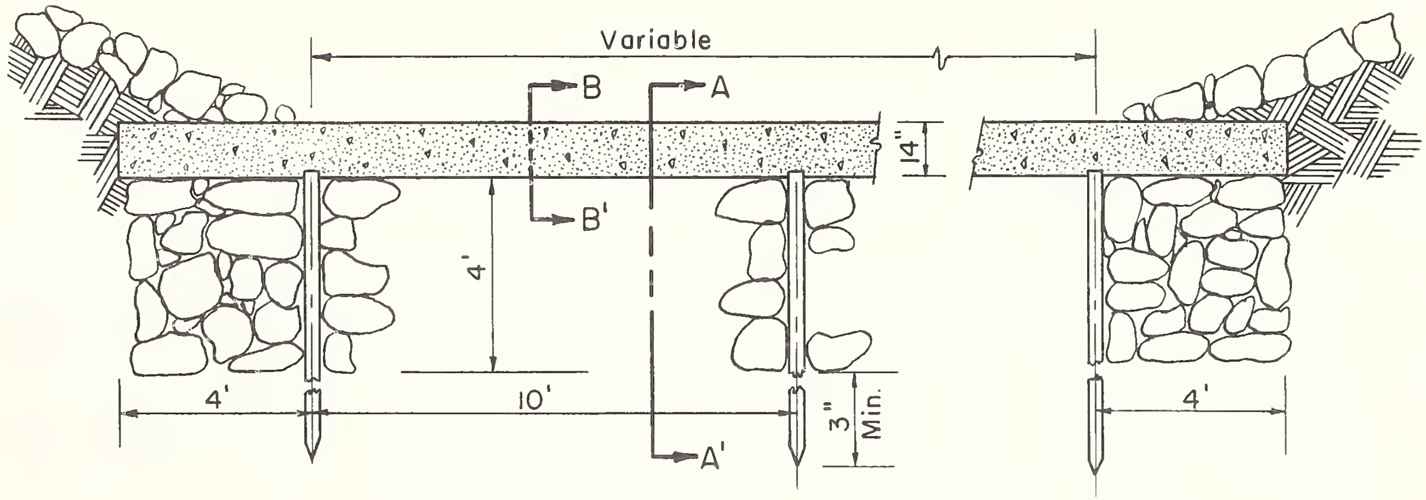


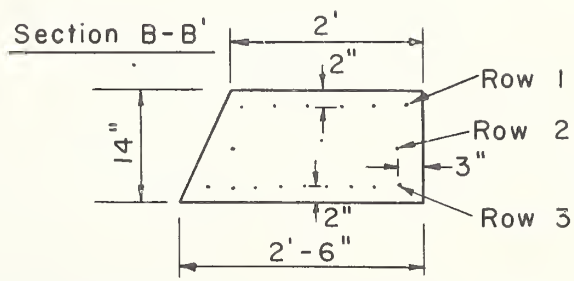
SKETCH SHOWING POSSIBLE EFFECT OF CHANNEL STRAIGHTENING ON GRADE

Figure 13

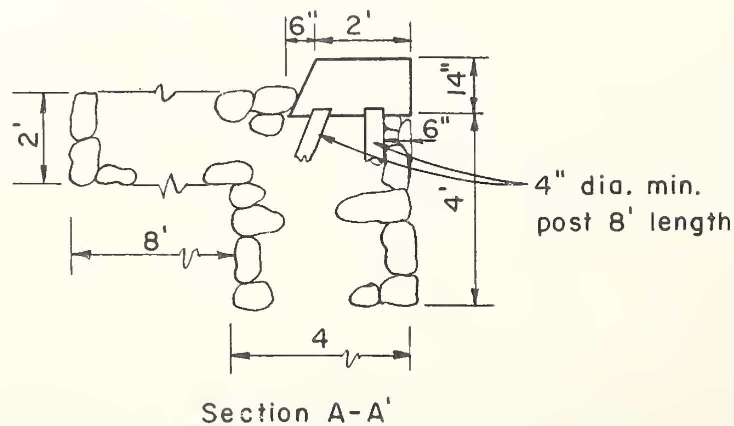
Figure 13

Typical riprapped bank



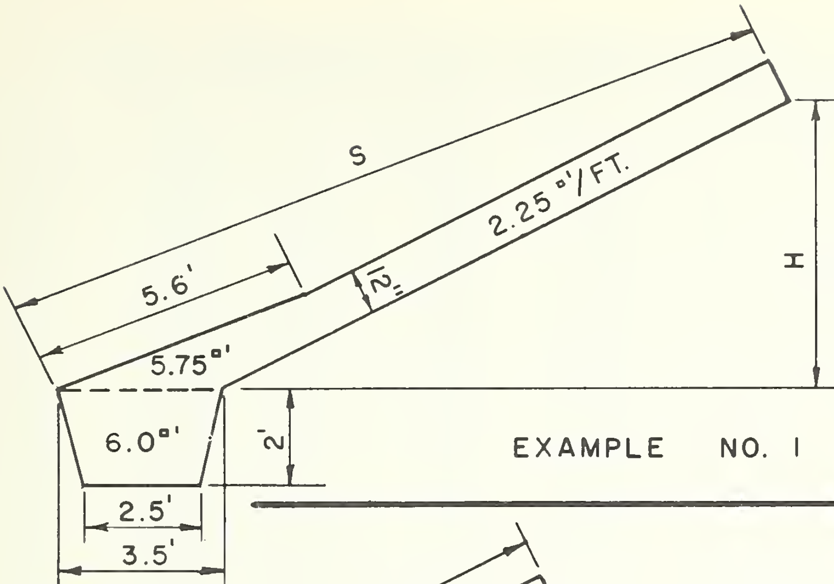


Steel Schedule		
Row 1	6	No. 3 bars
Row 2	2	No. 3 bars
Row 3	9	No. 5 bars



GRADE CONTROL SILL

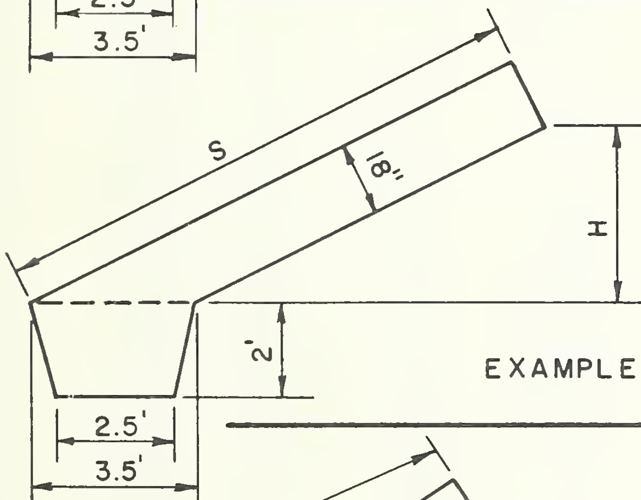
Figure 14



K=(H-2).083 + .472 = CU.YDS.
S=(H-2).25 + .84 = SQ.YDS.

12" RIP RAP — 1 ON 2 SLOPE

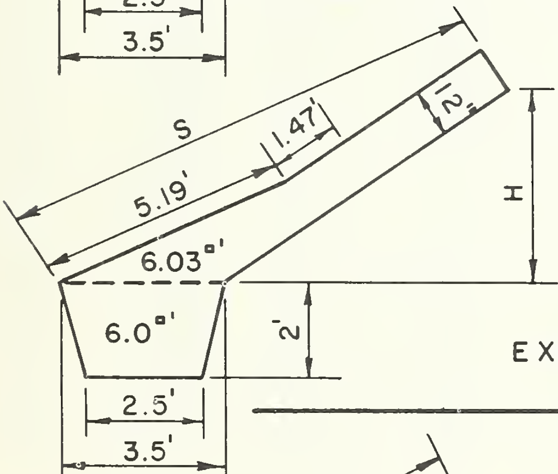
EXAMPLE NO. 1



S=(H-2).248 + .845 = SQ.YDS.
K=(H-2).13 + .573

18" RIP RAP – 1 ON 2 SLOPE

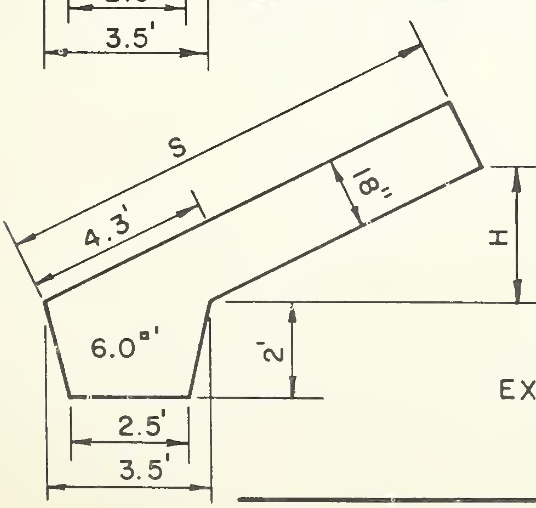
EXAMPLE NO. 2



S=(H-2) 1.80/9 + (5.19/9 + 1.47/9)
S=(H-2).20 + .740 = SQ.YDS.
K=(H-2).067 + .446 = CU.YDS.

12" RIP RAP – 1 ON 1 1/2 SLOPE

EXAMPLE NO. 3



S=(H-2).20 + .726 = SQ.YDS.
K=(H-2) 0.10 + .521 = CU.YDS.

18" RIP RAP – 1 ON 1 1/2 SLOPE

EXAMPLE NO. 4

TABLES FOR ESTIMATING QUANTITIES OF REVETMENT

12" RIP RAP - 1 ON 2 SLOPE - SEE EXAMPLE NO. 1

H	S	K	H	S	K	H	S	K
2.0	.844	.4720	5.9	1.819	.7957	9.8	2.794	1.1194
.1	.869	.4803	6.0	1.844	.8040	.9	2.819	1.1277
.2	.894	.4886	.1	1.869	.8123	10.0	2.844	1.1360
.3	.919	.4969	.2	1.894	.8206	.1	2.869	1.1443
.4	.944	.5052	.3	1.919	.8289	.2	2.894	1.1526
.5	.969	.5135	.4	1.944	.8372	.3	2.919	1.1609
.6	.994	.5218	.5	1.969	.8455	.4	2.944	1.1692
.7	1.019	.5301	.6	1.994	.8538	.5	2.969	1.1775
.8	1.044	.5384	.7	2.019	.8621	.6	2.994	1.1858
.9	1.069	.5467	.8	2.044	.8704	.7	3.019	1.1941
3.0	1.094	.5550	.9	2.069	.8787	.8	3.044	1.2024
.1	1.119	.5633	7.0	2.094	.8870	.9	3.069	1.2107
.2	1.144	.5716	.1	2.119	.8953	11.0	3.094	1.2190
.3	1.169	.5799	.2	2.144	.9036	.1	3.119	1.2273
.4	1.194	.5882	.3	2.169	.9119	.2	3.144	1.2356
.5	1.219	.5965	.4	2.194	.9202	.3	3.169	1.2439
.6	1.244	.6048	.5	2.219	.9285	.4	3.194	1.2522
.7	1.269	.6131	.6	2.244	.9368	.5	3.219	1.2605
.8	1.294	.6214	.7	2.269	.9451	.6	3.244	1.2688
.9	1.319	.6297	.8	2.294	.9534	.7	3.269	1.2771
4.0	1.344	.6380	.9	2.319	.9617	.8	3.294	1.2854
.1	1.369	.6463	8.0	2.344	.9700	.9	3.319	1.2937
.2	1.394	.6546	.1	2.369	.9783	12.0	3.344	1.3020
.3	1.419	.6629	.2	2.394	.9866	.1	3.369	1.3103
.4	1.444	.6712	.3	2.419	.9949	.2	3.394	1.3186
.5	1.469	.6795	.4	2.444	1.0032	.3	3.419	1.3269
.6	1.494	.6878	.5	2.469	1.0115	.4	3.444	1.3352
.7	1.519	.6961	.6	2.494	1.0198	.5	3.469	1.3435
.8	1.544	.7044	.7	2.519	1.0281	.6	3.494	1.3518
.9	1.569	.7127	.8	2.544	1.0364	.7	3.519	1.3601
5.0	1.594	.7210	.9	2.569	1.0447	.8	3.544	1.3684
.1	1.619	.7293	9.0	2.594	1.0530	.9	3.569	1.3767
.2	1.644	.7376	.1	2.619	1.0613	13.0	3.594	1.3850
.3	1.669	.7459	.2	2.644	1.0696	.1	3.619	1.3933
.4	1.694	.7542	.3	2.669	1.0779	.2	3.644	1.4016
.5	1.719	.7625	.4	2.694	1.0862	.3	3.669	1.4099
.6	1.744	.7708	.5	2.719	1.0945	.4	3.694	1.4182
.7	1.769	.7791	.6	2.744	1.1028	.5	3.719	1.4265
.8	1.794	.7874	.7	2.769	1.1111	.6	3.744	1.4348

18" RIP RAP - 1 ON 2 SLOPE - SEE EXAMPLE NO. 2

H	S	K	H	S	K	H	S	K
2.0	.8450	0.5730	5.9	1.8138	1.0784	9.8	2.7825	1.5839
.1	.8698	0.5860	6.0	1.8386	1.0914	.9	2.8074	1.5968
.2	.8947	0.5189	.1	1.8634	1.1044	10.0	2.8322	1.6098
.3	.9195	0.6119	.2	1.8883	1.1173	.1	2.8570	1.6228
.4	.9442	0.6248	.3	1.9131	1.303	.2	2.8819	1.6357
.5	.9692	0.6378	.4	1.9380	1.1432	.3	2.9067	1.6487
.6	.9940	0.6508	.5	1.9628	1.1562	.4	2.9316	1.6616
.7	1.0189	0.6637	.6	1.9876	1.1692	.5	2.9564	1.6746
.8	1.0437	0.6767	.7	2.0125	1.1821	.6	2.9812	1.6876
.9	1.0686	0.6896	.8	2.0373	1.1951	.7	3.0061	1.7005
3.0	1.0934	0.7026	.9	2.0622	1.2080	.8	3.0309	1.7135
.1	1.1182	0.7156	7.0	2.0870	1.2210	.9	3.0558	1.7264
.2	1.1431	0.7285	.1	2.1118	1.2340	11.0	3.0806	1.7394
.3	1.1679	0.7415	.2	2.1367	1.2469	.1	3.1054	1.7524
.4	1.1978	0.7544	.3	2.1615	1.2599	.2	3.1303	1.7653
.5	1.2176	0.7674	.4	2.1864	1.2728	.3	3.1551	1.7783
.6	1.2424	0.7804	.5	2.2113	1.2858	.4	3.1800	1.7912
.7	1.2673	0.7933	.6	2.2360	1.2988	.5	3.2048	1.8042
.8	1.2921	0.8063	.7	2.2609	1.3117	.6	3.2296	1.8172
.9	1.3170	0.8192	.8	2.2857	1.3247	.7	3.2545	1.8301
4.0	1.3418	0.8322	.9	2.3106	1.3376	.8	3.2793	1.8431
.1	1.3666	0.8452	8.0	2.3354	1.3506	.9	3.3042	1.8560
.2	1.3915	0.8581	.1	2.3602	1.3636	12.0	3.3290	1.8690
.3	1.4163	0.8711	.2	2.3851	1.3765	.1	3.3538	1.8820
.4	1.4412	0.8840	.3	2.4099	1.3895	.2	3.3787	1.8949
.5	1.4660	0.8970	.4	2.4348	1.4024	.3	3.4035	1.9079
.6	1.4908	0.9100	.5	2.4596	1.4154	.4	3.4284	1.9208
.7	1.5157	0.9229	.6	2.4844	1.4284	.5	3.4532	1.9338
.8	1.5405	0.9359	.7	2.5093	1.4413	.6	3.4780	1.9468
.9	1.5654	0.9488	.8	2.5341	1.4543	.7	3.5029	1.9597
5.0	1.5902	0.9618	.9	2.5590	1.4672	.8	3.5277	1.9727
.1	1.6150	0.9748	9.0	2.5838	1.4802	.9	3.5526	1.9856
.2	1.6399	0.9877	.1	2.6086	1.4932	10.0	3.5774	1.9986
.3	1.6647	1.0007	.2	2.6335	1.5061	.1	3.6022	2.0116
.4	1.6896	1.0136	.3	2.6583	1.5191	.2	3.6270	2.0246
.5	1.7144	1.0266	.4	2.6832	1.5320	.3	3.6518	2.0376
.6	1.7392	1.0396	.5	2.7080	1.5450	.4	3.6766	2.0506
.7	1.7641	1.0525	.6	2.7328	1.5580	.5	3.7014	2.0636
.8	1.7889	1.0655	.7	2.7577	1.5709	.6	3.7262	2.0766

12" RIP RAP - 1 ON 1 1/2 SLOPE - SEE EXAMPLE NO. 3

H	S	K	H	S	K	H	S	K
2.0	.74	.446	5.9	1.52	.7073	9.8	2.30	.9686
.1	.76	.4527	6.0	1.54	.7140	.9	2.32	.9753
.2	.78	.4594	.1	1.56	.7207	10.0	2.34	.9820
.3	.80	.4661	.2	1.58	.7274	.1	2.36	.9887
.4	.82	.4728	.3	1.60	.7341	.2	2.38	.9954
.5	.84	.4795	.4	1.62	.7408	.3	2.40	1.0021
.6	.86	.4862	.5	1.64	.7475	.4	2.42	1.0088
.7	.88	.4929	.6	1.66	.7542	.5	2.44	1.0155
.8	.90	.4996	.7	1.68	.7609	.6	2.46	1.0222
.9	.92	.5063	.8	1.70	.7676	.7	2.48	1.0289
3.0	.94	.5130	.9	1.72	.7743	.8	2.50	1.0359
.1	.96	.5197	7.0	1.74	.7810	.9	2.52	1.0423
.2	.98	.5264	.1	1.76	.7877	11.0	2.54	1.0490
.3	1.00	.5331	.2	1.78	.7944	.1	2.56	1.0557
.4	1.02	.5398	.3	1.80	.8011	.2	2.58	1.0624
.5	1.04	.5465	.4	1.82	.8078	.3	2.60	1.0691
.6	1.06	.5532	.5	1.84	.8145	.4	2.62	1.0758
.7	1.08	.5599	.6	1.86	.8212	.5	2.64	1.0825
.8	1.10	.5666	.7	1.88	.8279	.6	2.66	1.0892
.9	1.12	.5733	.8	1.90	.8346	.7	2.68	1.0959
4.0	1.14	.5800	.9	1.92	.8413	.8	2.70	1.1026
.1	1.16	.5867	8.0	1.94	.8480	.9	2.72	1.1093
.2	1.18	.5934	.1	1.96	.8547	12.0	2.74	1.1160
.3	1.20	.6001	.2	1.98	.8614	.1	2.76	1.1227
.4	1.22	.6068	.3	2.00	.8681	.2	2.78	1.1294
.5	1.24	.6135	.4	2.02	.8748	.3	2.80	1.1361
.6	1.26	.6202	.5	2.04	.8815	.4	2.82	1.1428
.7	1.28	.6269	.6	2.06	.8882	.5	2.84	1.1495
.8	1.30	.6336	.7	2.08	.8949	.6	2.86	1.1562
.9	1.32	.6403	.8	2.10	.9016	.7	2.88	1.1629
5.0	1.34	.6470	.9	2.12	.9083	.8	2.90	1.1696
.1	1.36	.6537	9.0	2.14	.9150	.9	2.92	1.1763
.2	1.38	.6604	.1	2.16	.9217	13.0	2.94	1.1830
.3	1.40	.6671	.2	2.18	.9284	.1	2.96	1.1897
.4	1.42	.6738	.3	2.20	.9351	.2	2.98	1.1964
.5	1.44	.6805	.4	2.22	.9418	.3	3.00	1.2031
.6	1.46	.6872	.5	2.24	.9485	.4	3.02	1.2098
.7	1.48	.6939	.6	2.26	.9552	.5	3.04	1.2165
.8	1.50	.7006	.7	2.28	.9619	.6	3.06	1.2232

18" RIP RAP - 1 ON 1 1/2 SLOPE - SEE EXAMPLE NO. 4

H	S	K	H	S	K	H	S	K
2.0	.726	.521	5.9	1.506	.911	9.8	2.286	1.301
.1	.746	.531	6.0	1.526	.921	.9	2.306	1.311
.2	.766	.541	.1	1.546	.931	10.0	2.326	1.321
.3	.786	.551	.2	1.566	.941	.1	2.346	1.331
.4	.806	.561	.3	1.586	.951	.2	2.366	1.341
.5	.826	.571	.4	1.606	.961	.3	2.386	1.351
.6	.846	.581	.5	1.626	.971	.4	2.406	1.361
.7	.866	.591	.6	1.646	.981	.5	2.426	1.371
.8	.886	.601	.7	1.666	.991	.6	2.446	1.381
.9	.906	.611	.8	1.686	1.001	.7	2.466	1.391
3.0	.926	.621	.9	1.706	1.011	.8	2.486	1.401
.1	.946	.631	7.0	1.726	1.021	.9	2.506	1.411
.2	.966	.641	.1	1.746	1.031	11.0	2.526	1.421
.3	.986	.651	.2	1.766	1.041	.1	2.546	1.431
.4	1.006	.661	.3	1.786	1.051	.2	2.566	1.441
.5	1.026	.671	.4	1.806	1.061	.3	2.586	1.451
.6	1.046	.681	.5	1.826	1.071	.4	2.606	1.461
.7	1.066	.691	.6	1.846	1.081	.5	2.626	1.471
.8	1.086	.701	.7	1.866	1.091	.6	2.646	1.481
.9	1.106	.711	.8	1.886	1.101	.7	2.666	1.491
4.0	1.126	.721	.9	1.906	1.111	.8	2.686	1.501
.1	1.146	.731	8.0	1.926	1.121	.9	2.706	1.511
.2	1.166	.741	.1	1.946	1.131	12.0	2.726	1.521
.3	1.186	.751	.2	1.966	1.141	.1	2.746	1.531
.4	1.206	.761	.3	1.986	1.151	.2	2.766	1.541
.5	1.226	.771	.4	2.006	1.161	.3	2.786	1.551
.6	1.246	.781	.5	2.026	1.171	.4	2.806	1.561
.7	1.266	.791	.6	2.046	1.181	.5	2.826	1.571
.8	1.286	.801	.7	2.066	1.191	.6	2.846	1.581
.9	1.306	.811	.8	2.086	1.201	.7	2.866	1.591
5.0	1.326	.821	.9	2.106	1.211	.8	2.886	1.601
.1	1.346	.831	9.0	2.126	1.221	.9	2.906	1.611
.2	1.366	.841	.1	2.146	1.231	13.0	2.926	1.621
.3	1.386	.851	.2	2.166	1.241	.1	2.946	1.631
.4	1.406	.861	.3	2.186	1.251	.2	2.966	1.641
.5	1.426	.871	.4	2.206	1.261	.3	2.986	1.651
.6	1.446	.881	.5	2.226	1.271	.4	3.006	1.661
.7	1.468	.891	.6	2.246	1.281	.5	3.026	1.671
.8	1.486	.901	.7	2.266	1.291	.6	3.046	1.681

Example 1 represents riprap placed on a 2:1 slope, 12" in thickness, with a toe trench. (See Figure 15).

Example 2 represents riprap placed on a 2:1 slope, 18" in thickness, with a toe trench. (See Figure 15).

Example 3 represents riprap placed on a 1-1/2:1 slope, 12" in thickness, with a toe trench. (See Figure 15).

Example 4 represents riprap placed on a 1-1/2:1 slope, 18" in thickness, with a toe trench. (See Figure 15).

Example 5 represents riprap on a 2:1 slope using a precast concrete toe. (See Figure 16).

Example 6 represents riprap on a 2:1 slope using a heavy toe section. (See Figure 16).

Examples 5 and 6 represent conditions that might be used on a stream with rock or shale bed.

Note that H is the vertical distance from the bottom of the subgrade slope to the elevation on the slope to which the riprap is placed. It does not include the thickness of the riprap. In actual practice, therefore, if H were 4 feet, the effective height of the riprap would be somewhat over 5 feet, if a 12" riprap were placed on slope.

Example (See Figure 17): A stream is actively eroding between points x and y along the outside of a bend. A closed traverse ABCDE is run in by a survey party so that traverse segments AB, BC, and CD roughly parallel the centerline of the stream. These traverse segments are run so that they are approximately 50 feet from the eroding bank. This setback is necessary to allow working space for equipment and area for sloping of bank without interfering with the line. Cross-sections are run in from this line at approximately fifty-foot intervals.

The cross-sections are plotted and a line and grade determined. The subgrade slope with toe section is marked on each section using a template.

The distance between sections is scaled from the plan along the line that the protected bank is to be placed. This line and measured distances along the bank should be shown on the sketch. These distances will be different than the distance between the sections at the traverse line due to the convergence of the sections due to curve of the stream channel.

H can be read directly from the sections.

Suppose, for example, the section shown in Example 1 is to be used.

A chart similar to the following can then be set up and the quantities taken from the table.

Section[1]	Distance on Line	H	S	Ave.(S)	K	Ave.(K)	Sq.Yd.	Cu.Yd.
0 + 00		4.8	1.544		.7044			
	50			1.7		.76	85.0	38.0
0 + 50		6.2	1.894		.8206			
	50			2.0		.87	100.0	43.5
1 + 00		7.5	2.219		.9285			
	48			2.3		.96	110.4	46.0
1 + 50		8.2	2.394		.9866			

[1]Sections and measurements should also be shown on the sketch.

To estimate the number of tons of stone in place, 2700 lbs. per cubic yard can be used. This is an average figure for riprap in place taking into account the void space.

20. GUIDE FOR DETERMINING ROCK SIZE FOR RIPRAP[2]

One of the problems facing engineers and others who work on streambank protection work is the determination of the size of stone that will be stable for a given stream condition.

There is included a chart, Drawing No. 7-L-16043, which may be used as a guide in making stone size determinations.

D_s, as given in the chart, is the size of rock in inches for which 25%, by weight, of the material is larger. This relationship was developed for materials having a specific gravity of 2.56.

Example: Determine the D_s size for riprap in a channel with the following characteristics.

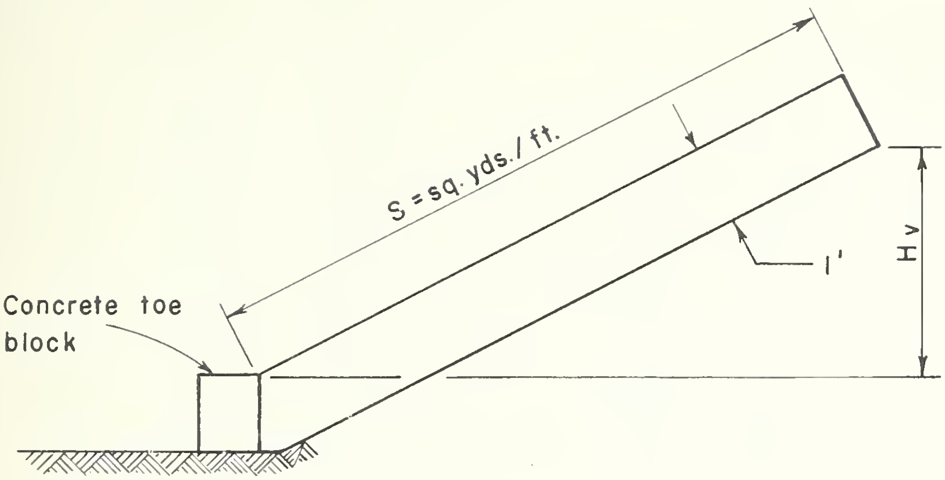
a. Slope - 0.010 ft/ft.
b. Side slopes - 2:1.
c. Depth of flow - 4.75 feet.
d. Curve radius - estimated 300'.
e. Water surface width - 45'.

Enter chart with slope 0.010 and follow line vertically to a point determined by interpolating between Depth of Flow lines, 4.75 feet, then follow horizontally to point on 2:1 slope line. Next follow line vertically to curve radius lines--in this case, 300/45 = 6.6 (use 6-9 line)--and then follow across horizontally and read D_s. Read 20". This is the nominal diameter in inches of rock for which 25% by weight is larger.

(This D_s size may seem of little value to the field technician since it is not feasible or practical for him to take a sample of riprap material and size it according to weight.)

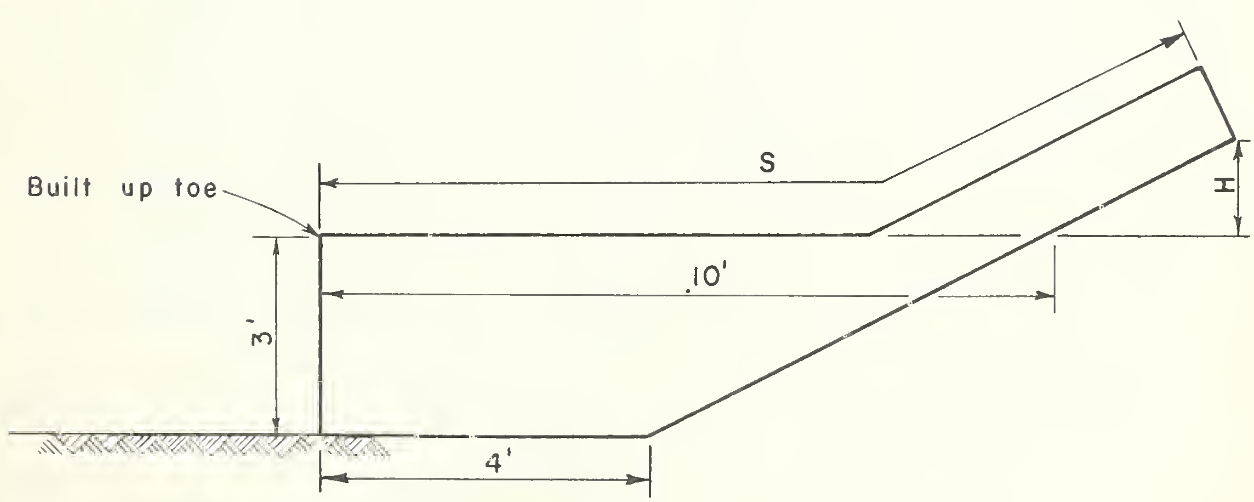
[2]Chart developed by E. J. Core, EWP Unit, Portland, with consultation of Professor Vito A. Vanoni, California Institute of Technology, using theory of Professor E. W. Lane.

The technician should inspect the material he proposes to use for riprap. If he cannot measure in a representative sample pile several stones with an approximate diameter of 20 inches and with several additional stones in evidence of greater diameter, then he can fairly well determine that the material would not be satisfactory. If, on the other hand, his check of the representative sample pile indicates there are several stones of a nominal diameter of 20 inches and greater, he can be fairly sure that the stone can be used for riprap under the conditions outlined in the example.



Example No. 5

See Figure 12



Example No. 6

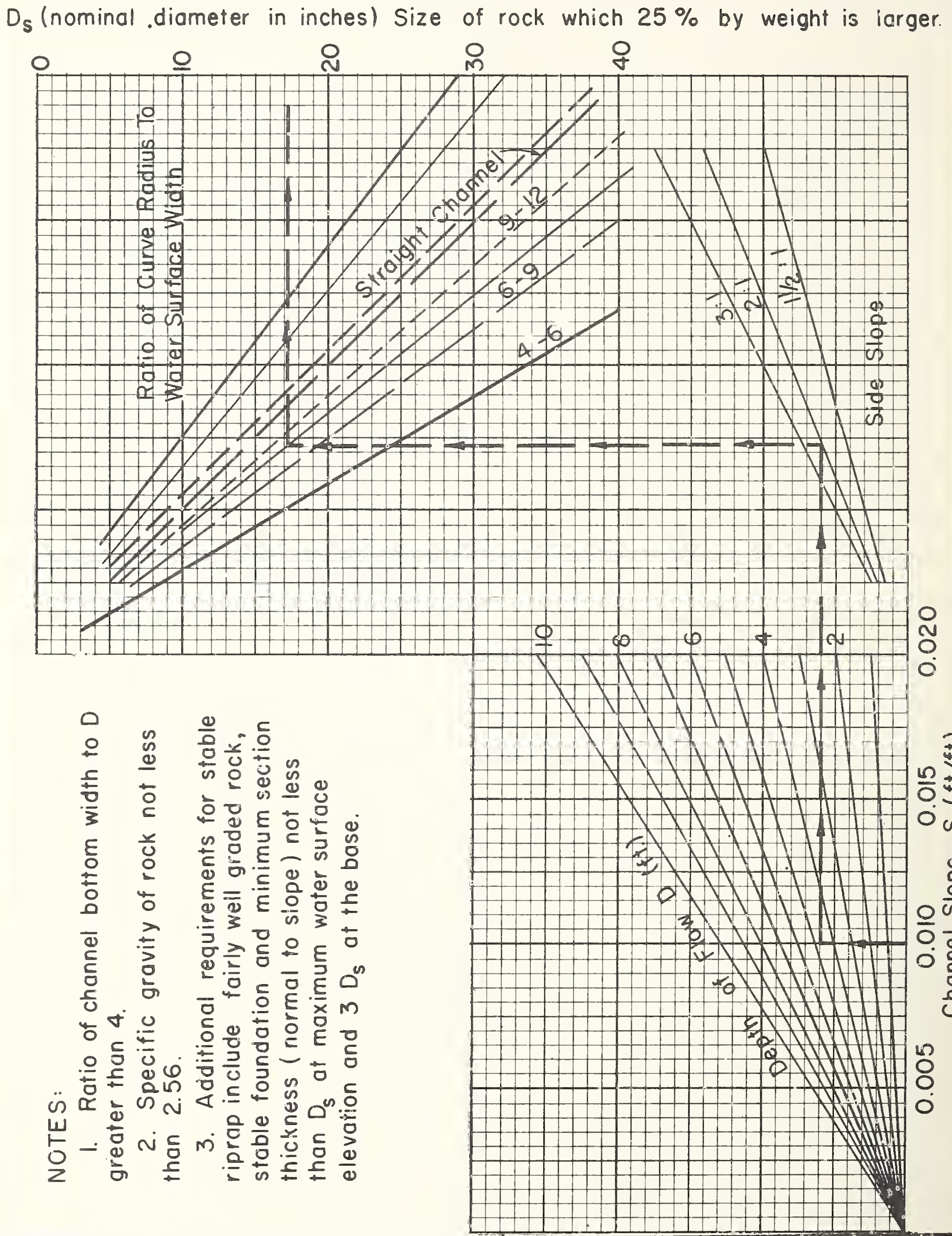
12" RIP RAP WITH CONCRETE TOE BLOCK 1 ON 2 SLOPE SEE EXAMPLE NO. 5

Hv	S		Hv	S		Hv	S	
1.0	.667		4.9	1.642		8.8	2.617	
.1	.692		5.0	1.667		.9	2.642	
.2	.717		.1	1.692		9.0	2.667	
.3	.742		.2	1.717		.1	2.692	
.4	.767		.3	1.742		.2	2.717	
.5	.792		.4	1.767		.3	2.742	
.6	.817		.5	1.792		.4	2.767	
.7	.842		.6	1.817		.5	2.792	
.8	.867		.7	1.842		.6	2.817	
.9	.892		.8	1.867		.7	2.842	
2.0	.917		.9	1.892		.8	2.867	
.1	.942		6.0	1.917		.9	2.892	
.2	.967		.1	1.942		10.0	2.917	
.3	.992		.2	1.967		.1	2.942	
.4	1.017		.3	1.992		.2	2.967	
.5	1.042		.4	2.017		.3	2.992	
.6	1.067		.5	2.042		.4	3.017	
.7	1.092		.6	2.067		.5	3.042	
.8	1.117		.7	2.092		.6	3.067	
.9	1.142		.8	2.117		.7	3.092	
3.0	1.167		.9	2.142		.8	3.117	
.1	1.192		7.0	2.167		.9	3.142	
.2	1.217		.1	2.192		11.0	3.167	
.3	1.242		.2	2.217		.1	3.192	
.4	1.267		.3	2.242		.2	3.217	
.5	1.292		.4	2.267		.3	3.242	
.6	1.317		.5	2.292		.4	3.267	
.7	1.342		.6	2.317		.5	3.292	
.8	1.367		.7	2.342		.6	3.317	
.9	1.392		.8	2.367		.7	3.342	
4.0	1.417		.9	2.392		.8	3.367	
.1	1.442		8.0	2.417		.9	3.392	
.2	1.467		.1	2.442		12.0	3.417	
.3	1.492		.2	2.467		.1	3.442	
.4	1.517		.3	2.492		.2	3.467	
.5	1.542		.4	2.517		.3	3.492	
.6	1.567		.5	2.542		.4	3.517	
.7	1.592		.6	2.567		.5	3.542	
.8	1.617		.7	2.592		.6	3.567	

12" RIP RAP WITH BUILT UP TOE SECTION 1 ON 2 SLOPE SEE EXAMPLE NO. 6

H	S	K	H	S	K	H	S	K
0.0	1.085	.8148	4.0	2.085	1.1468	8.0	3.085	1.4788
0.1	1.110	.8231	4.1	2.110	1.1551	8.1	3.110	1.4871
0.2	1.135	.8314	4.2	2.135	1.1634	8.2	3.135	1.4954
0.3	1.160	.8397	4.3	2.160	1.1717	8.3	3.160	1.5037
0.4	1.185	.8480	4.4	2.185	1.1800	8.4	3.185	1.5120
0.5	1.210	.8563	4.5	2.210	1.1883	8.5	3.210	1.5203
0.6	1.235	.8646	4.6	2.235	1.1966	8.6	3.235	1.5286
0.7	1.260	.8729	4.7	2.260	1.2049	8.7	3.260	1.5369
0.8	1.285	.8812	4.8	2.285	1.2132	8.8	3.285	1.5452
0.9	1.310	.8895	4.9	2.310	1.2215	8.9	3.310	1.5535
1.0	1.335	.8978	5.0	2.335	1.2298	9.0	3.335	1.5618
1.1	1.360	.9061	5.1	2.360	1.2381	9.1	3.360	1.5701
1.2	1.385	.9144	5.2	2.385	1.2464			
1.3	1.410	.9227	5.3	2.410	1.2547			
1.4	1.435	.9310	5.4	2.435	1.2630			
1.5	1.460	.9393	5.5	2.460	1.2713			
1.6	1.485	.9476	5.6	2.485	1.2796			
1.7	1.510	.9559	5.7	2.510	1.2879			
1.8	1.535	.9642	5.8	2.535	1.2962			
1.9	1.560	.9725	5.9	2.560	1.3045			
2.0	1.585	.9808	6.0	2.585	1.3128			
2.1	1.610	.9891	6.1	2.610	1.3211			
2.2	1.635	.9974	6.2	2.635	1.3294			
2.3	1.660	1.0057	6.3	2.660	1.3377			
2.4	1.685	1.0140	6.4	2.686	1.3460			
2.5	1.710	1.0223	6.5	2.710	1.3543			
2.6	1.735	1.0306	6.6	2.735	1.3626			
2.7	1.760	1.0389	6.7	2.760	1.3709			
2.8	1.785	1.0472	6.8	2.785	1.3792			
2.9	1.810	1.0555	6.9	2.810	1.3875			
3.0	1.835	1.0638	7.0	2.835	1.3958			
3.1	1.860	1.0721	7.1	2.860	1.4041			
3.2	1.885	1.0804	7.2	2.885	1.4124			
3.3	1.910	1.0887	7.3	2.910	1.4207			
3.4	1.935	1.0970	7.4	2.935	1.4290			
3.5	1.960	1.1053	7.5	2.960	1.4373			
3.6	1.985	1.1136	7.6	2.985	1.4456			
3.7	2.010	1.1219	7.7	3.010	1.4539			
3.8	2.035	1.1302	7.8	3.035	1.4622			
3.9	2.060	1.1385	7.9	3.060	1.4705			

ROCK SIZE FOR STABLE RIPRAP



NOTES:

1. Ratio of channel bottom width to D greater than 4.
2. Specific gravity of rock not less than 2.56.
3. Additional requirements for stable riprap include fairly well graded rock, stable foundation and minimum section thickness (normal to slope) not less than D_s at maximum water surface elevation and 3 D_s at the base.

REFERENCE "Design of Stable Channels" Transactions A.S.C.E 1955 Adapted From Curve By E.J. Core S.C.S. Portland, Oregon	U.S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE	DRAWING NO. 7-1-16043 SHEET 1 OF 1 DATE: July 1956